carried from one country to the other, or that both countries had obtained their standards from a common source.

But in the heavens we discover by their light, and by their light alone, stars so distant from each other that no material thing can ever have passed from one to another, and yet this light, which is to us the sole evidence of the existence of these distant worlds, tells us also that each of them is built up of molecules of the same kinds as those which we find on earth. A molecule of hydrogen, for example, whether in Sirius or in Arcturus, executes its vibrations in precisely the same time.

Each molecule, therefore, throughout the universe, bears impressed on it the stamp of a metric system as distinctly as does the metre of the Archives at Paris, or the double royal cubit of the Temple of Karnac.

No theory of evolution can be formed to account for the similarity of molecules, for evolution necessarily implies continuous change, and the molecule is incapable of growth or decay, of generation or destruction.

None of the processes of Nature, since the time when Nature began, have produced the slightest difference in the properties of any molecule. We are therefore unable to ascribe either the existence of the molecules or the identity of their properties to the operation of any of the causes which we call natural.

On the other hand, the exact quality of each molecule to all others of the same kind gives it, as Sir John Herschel has well said, the essential character of a manufactured article, and precludes the idea of its being eternal and self-existent.

Thus we have been led, along a strictly scientific path, very near to the point at which Science must stop. Not that Science is debarred from studying the internal mechanism of a molecule which she cannot take to pieces, any more than from investigating an organism which she cannot put together. But in tracing back the history of matter Science is arrested when she assures herself, on the one hand, that the molecule has been made, and on the other that it has not been made by any of the processes we call natural.

Science is incompetent to reason upon the creation of matter itself out of nothing. We have reached the utmost limit of our thinking faculties when we have admitted that because matter cannot be eternal and self-existent it must have been created.

It is only when we contemplate, not matter in itself, but the form in which it actually exists, that our mind finds something on which it can lay hold.

That matter, as such, should have certain fundamental properties—that it should exist in space and be capable of motion, that its motion should be persistent, and so on, are truths which may, for anything we know, be of the kind which metaphysicians call necessary. We may use our knowledge of such truths for purposes of deduction but we have no data for speculating as to their origin.

But that there should be exactly so much matter and no more in every molecule of hydrogen is a fact of a very different order. We have here a particular distribution of matter—a *collocation* —to use the expression of Dr. Chalmers, of things which we have no difficulty in imagining to have been arranged otherwise.

The form and dimensions of the orbits of the planets, for instance, are not determined by any law of nature, but depend upon a particular collocation of matter. The same is the case with respect to the size of the earth, from which the standard of what is called the metrical system has been derived. But these astronomical and terrestrial magnitudes are far inferior in scientific importance to that most fundamental of all standards which forms the base of the molecular system. Natural causes, as we know, are at work, which tend to modify, if they do not at length destroy, all the arrangements and dimensions of the earth and the whole solar system. But though in the course of ages catastrophes have occurred and may yet occur in the heavens, though ancient systems may be dissolved and new systems evolved out of their ruins, the molecules out of which these systems are built—the foundation stones of the material universe—remain unbroken and unworn.

They continue this day as they were created, perfect in number and measure and weight, and from the ineffaceable characters impressed on them we may learn that those aspirations after accuracy in measurement, truth in statement, and justice in action, which we reckon among our noblest attributes as men, are ours because they are essential constituents of the image of Him Who in the beginning created, not only the heaven and the earth, but the materials of which heaven and earth consist.

Table of Molecular Data.

		Hydrogen.	Oxygen.	Carbonic oxide.	Carbonic acid.
Rank I.	Mass of molecule (hydrogen = 1)	1	16	14	22
	Velocity (of mean square), metres per second at 0° C.	1859	465	497	396
Rank II.	Mean path, tenth-metres.	965	560	482	379
	Collisions in a second, (millions)	17750	7646	9489	9720
Rank III.	Diameter, tenth-metre	5·8	7·6	8·3	9·3
	Mass, twenty-fifth-grammes.	46	736	644	1012

Table of Diffusion: $\frac{(\text{centimetre})^2}{\text{second}}$ measure.

	Calculated	Observed.	
H & O	0·7086	0·7214	Diffusion of matter observed by Loschmidt.
H & CO	0·6519	0·6422	
H & CO_2	0·5575	0·5558	
O & CO	0·1807	0·1802	
O & CO_2	0·1427	0·1409	
CO & CO_2	0·1386	0·1406	
H	1·2990	1·49	Diffusion of momentum Graham and Meyer.
O	0·1884	0·213	
CO	0·1748	0·212	
CO_2	0·1087	0·117	
Air		0·256	Diffusion of temperature observed by Stefan.
Copper		1·077	
Iron		0·183	

Cane sugar in water	0·00000365	Voit.
Diffusion in a day	0·3144	
Salt in water . .	0·00000116	Fick.

FUEL *

IN accepting the invitation of the Council of the British Association to deliver an address to the operative classes of this great industrial district, I felt that I was undertaking no easy task. Having to speak on behalf of the Association, and in the presence of many of its most distinguished members, I am bound to treat my subject scientifically, but I have to bear in mind at the same time that I am addressing myself to men unquestionably of good intelligence, but without that scientific training which has almost created a language of its own.

It is no consolation for me to think, that those who have taken a similar task upon themselves in former years, have admirably succeeded in divesting highly scientific subjects of the formalism in which they are habitually clothed. The very names of these men—Tyndall, Huxley, Miller, Lubbock, and Spottiswoode—are such as to preclude in me all idea of rivalry, but I hope to profit by their example, and to remember that truth must always be simple, and that it is only where knowledge is imperfect that scientific formulæ must take the place of plain statements.

The subject matter of my discourse is "Fuel;" a matter with which every one of us has become familiarised from his infancy, but which nevertheless is but little understood even by those who are most largely interested in its applications; it involves considerations of the highest *à priori* interest, both from a scientific and a practical point of view.

I purpose to arrange my subject under five principal heads:—

1. What is fuel?
2. Whence is fuel derived?
3. How should fuel be used?
4. The coal question of the day.
5. Wherein consists the fuel of the sun?

What is fuel?—Some of you may have already said within yourselves that it is but wasted time to enlarge upon such a theme, since all know that fuel is coal drawn from the earth from deposits, with which this country especially has been bountifully supplied; why disturb our plain understanding by scientific definitions which will neither reduce the cost of coal, nor make it last longer on our domestic hearth?

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* Lecture delivered before the British Association at Bradford, by Dr. Siemens.

Yet I must claim your patience for a little, lest, if we do not first agree upon the essential nature of fuel, we may afterwards be at variance in discussing its origin and its uses, the latter at any rate being of practical interest, and a subject worthy of your most attentive consideration.

Fuel, then, in the ordinary acceptation of the term, is carbonaceous matter, which may be in the solid, the liquid, or in the gaseous condition, and which, in combining with oxygen, gives rise to the phenomenon of heat. Commonly speaking, this development of heat is accompanied by flame, because the substance produced in combustion is gaseous. In burning coal, for instance, on a fire-grate, the oxygen of the atmosphere enters into combination with the solid carbon of the coal and produces carbonic acid—a gas which enters the atmosphere, of which it forms a necessary constituent, since without it the growth of trees and other plants would be impossible. But combustion is not necessarily accompanied by flame, or even by a display of intense heat. The metal magnesium burns with a great display of light and heat, but without flame, because the product of combustion is not a gas but a solid, viz. oxide of magnesia. Again, metallic iron, if in a finely divided state, ignites when exposed to the atmosphere, giving rise to the phenomena of heat and light without flame, because the result of combustion is iron oxide or rust; but the same iron, if presented to the atmosphere—more especially to a damp atmosphere—in a solid condition, does not ignite, but is nevertheless gradually converted into metallic oxide or rust as before.

Here, then, we have combination without the phenomena either of flame or light; but by careful experiment we should find that heat is nevertheless produced, and that the amount of heat so produced precisely equals that obtained more rapidly in exposing spongy iron to the action of oxygen. Only, in the latter case the heat is developed by slow degrees, and is dispersed as soon as produced; whereas in the former the rate of production exceeds the rate of dispersion, and heat, therefore, accumulates to the extent of raising the mass to redness. It is evident from these experiments that we have to widen our conception, and call fuel "any substance which is capable of entering into combination with another substance, and in so doing gives rise to the phenomenon of heat."

In thus defining fuel, it might appear at first sight that we should find upon our earth a great variety, and an inexhaustible supply of substances that might be ranged under this head; but a closer investigation will soon reveal the fact that its supply is, comparatively speaking, extremely limited.

In looking at the solid crust of the earth, we find it to be composed for the most part of siliceous, calcareous, and magnesian rock; the former, silica, consisting of the metal silicon combined with oxygen, and is therefore not fuel, but rather a burnt substance which has parted with its heat of combustion ages ago; the second limestone, being carbonate of lime, or the combination of two substances, viz., oxide of calcium and carbonic acid, both of which are essentially products of combustion, the one of the metal calcium and the other of carbon; and the third, magnesia, being the substance magnesium, which I have just burnt before you, and which, further combined with lime, constitutes dolomite rock, of which the Alps are mainly composed. All the commoner metals, such as iron, zinc, tin, alumina, sodium, &c., we find in nature in an oxidised or burnt condition; and the only metallic substances that have resisted the intense oxidising action that must have prevailed at one period of the earth's creation are the so-called precious metals, gold, platinum, iridium, and to some extent also silver and copper. But what about the oceans of water, which have occasionally been cited as representing a vast store of heat-producing power ready for our use when coal shall be exhausted? Not many months ago, indeed, on the occasion of a water-gas company being formed, statements to this effect could be seen in some of our leading papers. Nothing, however, could be more fallacious. When hydrogen burns, doubtless a great development of heat ensues, but water is already the result of this combustion (which took place upon the globe before the ocean was formed), and the separation of these two substances would take precisely the same amount of heat as was originally produced in the combustion. It will thus be seen that both the solid and fluid constituents of our earth, with the exception of coal, of naphtha (which is a mere modification of coal), and the precious metals, are products of combustion, and therefore the very reverse of fuel. Our earth may indeed be looked upon as "a ball of cinder, rolling eternally through space," but happily in company with another celestial body—the sun—whose glorious beams are the physical cause of everything that moves and lives, or that has the power within itself of imparting life, heat, or motion. The invigorating influence is made perceptible to our senses in the form of heat, but it is fair to ask, what is heat, that it should be capable of coming to us from the sun, and of being treasured up in our fuel deposits both below and on the surface of the earth?

If this inquiry had been put to me thirty years ago, I should have been much perplexed. By reference to books on Physical Science, I should have learnt that heat was a subtle fluid which, somehow or other, had taken up its residence in the fuel, and which, upon ignition of the latter, was sallying forth either to vanish or to abide elsewhere; but I should not have been able to associate the two ideas of combustion and development of heat by any intelligible principle in nature, or to suggest any process by which it could have been derived from the sun and petrified, or, as the empty phrase ran, rendered latent in the fuel.

It is by the labours of Meyer, Joule, Clausius, Ranken, and other modern physicists, that we are enabled to give to heat its true significance.

Heat, according to the "dynamical theory," is neither more nor less than motion amongst the particles of the substance heated, which motion, when once produced, may be changed in its direction and its nature, and thus be converted into mechanical effect, expressible in foot pounds, or horse power. By intensifying this motion among the particles, it is made evident to our visual organ by the emanation of light, which again is neither more nor less than vibratory motion imparted by the ignited substance to the medium separating us from the same. According to this theory, which constitutes one of the most important advances in science of the present century, heat, light, electricity, and chemical action are only different manifestations of "energy of matter," mutually convertible, but as indestructible as matter itself.

Energy exists in two forms, dynamic or "kinetic energy," or force manifesting itself to our senses as weight in motion, as sensible heat, or as an active electrical current; and "potential energy," or force in a dormant condition. In illustration of these two forms of energy, I will take the case of lifting a weight, say one pound one foot high. In lifting this weight "kinetic muscular energy" has to be exercised in overcoming the force of gravitation of the earth. The pound weight when supported at the higher level to which it has been raised, represents potential energy to the amount of one unit or foot pound. This potential energy may be utilised in imparting motion to mechanism during its descent, whereby a unit amount of "Work" is accomplished. A pound of carbon then, when raised through the space of one foot from the earth, represents, mechanically speaking, a unit quantity of energy, but the same pound of carbon being separated or lifted away from oxygen, to which it has a very powerful attraction, is capable of developing no less than 11,000,000 foot pounds or unit quantities of energy whenever the bar to their combination, namely excessive depression of temperature, is removed; in other words, the mechanical energy set free in the combustion of one pound of pure carbon is the same as would be required to raise 11,000,000 pounds weight one foot high, or as would sustain the work which we call a horse power during 5 hours 33 minutes. We thus arrive at once at the utmost limit of work which we can ever hope to accomplish by the combustion of one pound of carbonaceous matter, and we shall presently see how far we are still removed in our steam engine practice from this limit of perfection.*

The following illustrations will show the convertibility of the different forms of energy. If I let the weight of a hammer descend in rapid succession upon a piece of iron it becomes hot, and on beating a nail thus vigorously and skilfully for a minute it will be redhot. In this case the mechanical force developed in the arm by the combustion of carbonaceous muscular fibre is converted into heat. Again, in compressing the air in a fire syringe rapidly ignition of a piece of tinder is obtained. Again, in passing an electrical current through the platinum wire it is directly converted into heat, which is manifested by ignition of the wire, whereas the thermopile gives an illustration of the conversion of heat into electricity. The heat of combustion is the result of the chemical combination of two substances; but does it not follow from this that oxygen is a combustible as well as the carbonaceous substance which goes by the name of fuel? This is, unquestionably, the case, and if our atmosphere was composed of a carbonaceous gas we should have to conduct our oxygen through tubes and send it out through burners to supply us with light and heat, as will be seen by the experiment in which I burn a jet of atmospheric air in a transparent globe filled with common lighting gas; but we could not exist under such inverted conditions, and may safely strike out oxygen and analogous substances such as chlorine from the list of fuels.

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* In burning 1 lb. of carbon in the presence of free oxygen, carbonic acid is produced and 14.500 units of heat (1 lb. of water raised through 1° Fah.) are liberated. Each unit of heat is convertible (as proved by the deductions of Meyer and the actual measurements of Joule) into 774 units of force or mechanical energy; hence 1 lb. of carbon represents really 14,500 × 774 = 11,223,000 units of potential energy.

We now approach the second part of our inquiry—Whence is fuel derived?

The rays of the sun represent energy in the form of heat and light, which is communicated to our earth through the transparent medium which must necessarily fill the space between us and our great luminary. If these rays fall upon the growing plant, their effect disappears from direct recognition by our senses, inasmuch as the leaf does not become heated as it would if it was made of iron or dead wood, but we find a chemical result accomplished, viz., carbonic acid gas which has been absorbed by the leaf of the tree from the atmosphere, is there "dissociated," or separated into its elements carbon and oxygen, the oxygen being returned to the atmosphere, and the carbon retained to form the solid substance of the tree.

It is thus clearly shown that the sun has to impart 11,000,000 units of energy to the tree for the formation of one pound of carbon in the shape of woody fibre, and that these 11,000,000 units of energy will be simply resuscitated when the wood is burnt, or again combined with oxygen to form carbonic acid.

Fuel, then, is derived through solar energy acting on the surface of our earth.

But what about the stores of mineral fuel, of coal, which we find within its folds? How did they escape the general combustion which, as we have seen, has consumed all other elementary substances? The answer is a simple one. These deposits of mineral fuel are the results of primeval forests, formed in the manner of to-day through the agency of solar rays, and covered over with earthy matter in the many inundations and convulsions of the globe's surface, which must have followed the early solidification of its surface. Thus our deposits of coal may be looked upon as the accumulation of potential energy derived directly from the sun in former ages, or as George Stephenson, with a sagacity of mind in advance of the science of his day, answered, when asked what was the ultimate cause of motion of his locomotive engine, "that it went by the bottled-up rays of the sun."

It follows from these considerations that the amount of potential energy available for our use is confined to our deposits of coal, which, as appears from the exhaustive inquiries lately made by the Royal Coal Commission are still large indeed, but by no means inexhaustible, if we bear in mind that our requirement will be ever on the increase and that the getting of the coal will become from year to year more difficult as we descend to greater depth. To these stores must be reckoned lignite and peat, which, although not coal, are nevertheless the result of solar energy, attributable to a period of the earth's creation subsequent to the formation of the coal beds, but anterior to our own days.

In discussing the necessity of using our stores of fuel more economically, I have been met by the observation that we need not be anxious about leaving fuel for our descendants—that the human mind would surely invent some other source of power when coal should be exhausted, and that such a source would probably be discovered in electricity. I heard such a suggestion publicly made only a few weeks back at a meeting of the International Jury at Vienna, and could not refrain from calling attention to the fact that electricity is only another form of energy, that could no more be created by man than heat could, and involved the same recourse to our accumulated stores.

If our stores of coal were to ebb, we should have recourse, no doubt, to the force radiating from the sun from day to day; and it may be as well for us to consider, what is the extent of that force, and what our means of gathering and applying it. We have, then, in the first place, the accumulation of solar energy upon our earth's surface by the decomposition of carbonic acid in plants, a source which we know by experience suffices for the human requirements in thinly-populated countries, where industry has taken only a slight development. Wherever population accumulates, however, the wood of the forest no longer suffices even for domestic requirements, and mineral fuel has to be transported from great distances.

The sun's rays produce, however, other effects besides vegetation, and amongst these, evaporation is the most important as a source of available power. By the solar rays, an amount of heat is imparted to our earth that would evaporate yearly a lake of water fourteen feet deep. A considerable proportion of this heat is actually expended in evaporating sea water, producing steam or vapour, which falls back upon the entire surface of both land and sea in the form of rain. The portion which falls upon the elevated land flows back towards the sea in the form of rivers, and in its descent its weight may be utilised to give motion to machinery. Water power, therefore, is also the result of solar energy, and an elevated lake may indeed be looked upon as fuel, in the sense of its being a weight lifted above the sea level through its prior expansion into steam.

This source of power has also been largely resorted to, and might be utilised to a still greater extent in mountainous countries; but it naturally so happens that the great centres of industry are in the plains, where the means of transport are easy, and the total amount of available water-power in such districts is extremely limited.

Another result of solar energy are the winds, which have been utilised for the production of power. This source of power is, indeed, very great in the aggregate, but its application is attended with very great inconvenience. It is proverbial that there is nothing more uncertain than the wind, and when we were dependent upon windmills for the production of flour, it often happened that whole districts were without that necessary element to our daily existence. Ships also, relying upon the wind for their propulsion through the sea, are often becalmed for weeks, and so gradually give preference to steam-power on account of its greater certainty. It has been suggested of late years to utilise the heat of the sun by the accumulation of its rays into a focus by means of gigantic lenses, and to establish steam-boilers in such foci. This would be a most direct utilisation of solar energy, but it is a plan which would hardly recommend itself in this country, where the sun is but rarely seen, and which even in a country like Spain would hardly be productive of useful, practical results.

There is one more natural source of energy available for our uses, which is rather cosmical than solar, viz., the tidal wave. This might also be utilised to very considerable extent in an island country facing the Atlantic seas, like this, but its utilisation on a large scale is connected with great practical difficulty and expenditure, on account of the enormous area of tidal basin that would have to be constructed.

In passing in review these various sources of energy which are still available to us, after we have run through our accumulated capital of potential energy in the shape of coal, it will have struck you that none of them would at all supply the place of our willing and ever-ready slave, the steam-engine; nor would they be applicable to our purposes of locomotion, although means might possibly be invented of storing and carrying potential energy in other forms. But it is not force alone that we require, but heat for smelting our iron and other metals, and the accomplishment of other chemical purposes. We also need a large supply for our domestic purposes. It is true that with an abundant supply of mechanical force we could manufacture heat, and thus actually accomplish all our purposes of smelting, cooking, and heating, without the use of any combustible matter; but such conversion would be attended with so much difficulty and expenditure, that one cannot conceive human prosperity under such laborious and artificial conditions.

We come now to the question—How should fuel be used, and I propose to illustrate this by three examples which are typical of the three great branches of consumption.

a. The production of steam power.
b. The domestic hearth.
c. The metallurgical furnace.

I have represented on a diagram two steam cylinders of the same internal dimensions, the one being what is called a high-pressure steam cylinder, provided with the ordinary slide-valve for the admission and discharge of steam into the atmosphere, and the other so arranged as to work expansively (being provided with the Carless variable expansion gear) and working in connection with a condenser. I have also shown two diagrams of the steam pressures at each part of the stroke, assuming in both cases the same initial steam pressure of 60 lbs. per square inch above the atmospheric pressure, and the same load upon the engine. They show that in the latter case the same amount of work is accomplished by filling the cylinder roughly speaking up to one-third part of the length as in the other by filling it entirely. Here we have then an easy and feasible plan of saving two-thirds of the fuel used in working an ordinary high-pressure engine, and yet probably the greater number of the engines now actually at work are of the wasteful type. Nor are the indications of theory in this case (or in any other when properly interpreted) disproved by practice; on the contrary, an ordinary non-expansive non-condensing engine requires commonly a consumption of from 10 to 12 lbs. per horse-power per hour, whereas a good expansive and condensing engine accomplishes the same amount of work with 2 lbs. of coal per hour, the reason for the still greater economy being, that the cylinder of the good engine is properly protected by means of a steam-jacket and lagging against loss by condensation within the working cylinder, and that more care is generally bestowed upon the boiler and the parts of the engine, to ensure their proper working condition.

A striking illustration of what can be accomplished by way of accuracy in a short space of time was brought to light by the Institute of Mechanical Engineers, over which at present I have the honour to preside. In holding their annual general meeting in Liverpool in 1863, they instituted a careful inquiry into the consumption by the best engines in the Atlantic Steam Service, and the result showed that it fell in no case below 4½ lbs. per indicated horse power per hour. Last year they again assembled with the same object in view in Liverpool, and Mr. Bramwell produced a table showing that the average consumption by 17 good examples of compound expansive engines did not exceed 2¼ lbs. per indicated horse power per hour. Mr. E. A. Cowper has proved a consumption not exceeding 1½ lbs. per indicated horse power per hour in a compound marine engine constructed with an intermediate superheating vessel, in accordance with his plans, nor are we likely to stop long at this point of comparative perfection, for in the early portion of my address I have endeavoured to prove that the theoretical perfection would only be attained if an indicated horse power was produced with $\frac{1}{5\cdot5}$ lbs. of pure carbon, or say ¼ lb. of ordinary steam coal.

Here then we have two distinct margins to work upon, the one up to the limit of say 2 lbs. per horse power per hour, which has been practically reached in some and may be reached in all cases, and the other up to the theoretical limit of ¼ lb. per horse power per hour which can never be absolutely reached, but which inventive power may and will enable us to approach!

Domestic Consumption—The wastefulness of the domestic hearth and kitchen fire is self-evident. Here only the heat radiated from the fire itself is utilised, and the combustion is generally extremely imperfect, because the iron back and excessive supply of cold airs, check combustion before it is half completed. We know that we can heat a room much more economically by means of a German stove, but to this it may be very properly objected that it is cheerless, because we do not see the fire or feel its drying effect on our damp clothing; it does not provide, moreover, in a sufficient degree for ventilation, and makes the room feel stuffy. These are, in my opinion, very potent objections, and economy would not be worth having if it could only be obtained at the expense of health and comfort. But there is at least one grate that combines an increased amount of comfort with reasonable economy, and which, although accessible to all, is as yet very little used. I refer to Captain Galton's "Ventilating Fireplace," of which you observe a diagram upon the wall. This fireplace does not differ in external appearance from an ordinary grate, except that it has a higher brick back, which is perforated at about mid-height to admit warmed air into the fire to burn a large proportion of the smoke which is usually sent up the chimney unburnt, for no better purpose than to poison the atmosphere we have to breathe.

The chief novelty and merit of Captain Galton's fireplace consists, however, in providing a chamber at the back of the grate, into which air passes directly from without, becomes moderately heated (to 84° Fah.), and, rising in a separate flue, is injected into the room under the ceiling with a force due to the heated ascending flue. A plenum of pressure is thus established within the room whereby indraughts through doors and windows are avoided, and the air is continually renewed by passing away through the fireplace chimney as usual. Thus the cheerfulness of an open fire, the comfort of a room filled with fresh but moderately warmed air, and great economy of fuel, are happily combined with unquestionable efficiency and simplicity; and yet the grate is little used, although it has been fully described in papers communicated by Captain Galton, and in an elaborate report made by General Morin, le Directeur du Conservatoire des Arts et Metiers of Paris, which has also appeared in the English language.

The slowness with which this unquestionable improvement finds practical application is due, in my opinion, to two circumstances,—the one is, that Captain Galton did not patent his improvement, which makes it nobody's business to force it into use, and the other may be found in the circumstance that houses are, to a great extent, built only to be sold and not to be lived in. A builder thinks it a good speculation to construct a score of houses after a cheap design, in order to sell them, if possible, before completion, and the purchaser immediately puts up the standard bill of "Desirable Residences to Let." You naturally would think that in taking such a house you had only to furnish it to your own mind, and be in the enjoyment of all reasonable creature comfort from the moment you enter the same. This fond hope is destined, however, to cruel disappointment; the first evening you turn on the gas, you find that although the pipes are there, the gas prefers to pass out by the joints into the room instead of by the burners; the water in like manner takes its road through the ceiling, bringing down with it a patch of plaster on to your carpet. But worst of all, the fire-grates (of a size irrespective, probably, of the size of the room), absolutely refuse to avail themselves of the chimney flues preferring to send the volumes of smoke into the room. Plumbers and chimney doctors are now put into requisition, pulling up floors, dirtying carpets, and putting up gaunt-looking chimney-pots; the grates themselves have to be altered again and again, until by slow degrees the house becomes habitable in a degree, although you now only become fully aware of innumerable drawbacks of the arrangements adopted. Nevertheless, the house has been an excellent one to sell, and the builder adopts the same pattern for another block or two in an increasing neighbourhood. Why should this builder adopt Captain Galton's fireplace? It will not cost him much, it is true, and it will save the tenant a great deal in his annual coal bill, not to speak of the comfort it would give him and his family; but nobody demands it of him, it would give him some trouble to arrange his details and subcontracts, which are all settled beforehand, and so he goes on building and selling houses in the usual routine way. Nor will this state of things be altered until the dwellers in houses will take the matter in hand, and absolutely refuse to put up with builders' ways, or, what is still better, get builders who will put up houses in their way. This is done to some extent by building societies, but there is as yet too much of the old leaven left in the trade, and the question itself too little understood.

Consumption in Smelting Operations.—We now come to the third branch of consumption, the smelting or metallurgical furnace, which consumes about 40,000,000 of the 120 millions of the fuel produced. Here also is great room for improvement, the actual fuel consumed in heating a ton of iron up to the welding point or of melting a ton of steel is more in excess of the theoretical quantity required for these purposes than is the case with regard to the production of steam power and to domestic consumption. Taking the specific heat of iron at ·114 and the welding heat at 2,700° F. it would require 2,700 × ·144—307 heat units to heat 1 lb. of iron. A pound of pure carbon developes 14,500 heat units, a pound of common coal 12,000, and therefore one ton of coal should bring 39 tons of iron up to the welding point. In an ordinary re-heating furnace a ton of coal heats only 1⅔ ton of iron, and therefore produces only $\frac{1}{23}$rd part of the maximum theoretical effect. In melting one ton of steel in pots 2½ tons of coke are consumed, and taking the melting point of steel at 3,600° F. the specific heat at ·119 it takes ·119 × 3,600 = 428 heat units to melt a pound of steel, and taking the heat producing power of common coke also at 12,000 units, one ton of coke ought to be able to melt 28 tons of steel. The Sheffield pot steel melting furnace therefore only utilises $\frac{1}{70}$th part of the theoretical heat developed in the combustion. Here therefore is a very wide margin for improvement, to which I have specially devoted my attention for many years, and not without the attainment of useful results. I have since the year

1846, or very shortly after the first announcement of the dynamical theory, devoted my attention to a realisation of some of the economic results which that theory rendered feasible. I fixed upon the regenerator as the appliance which, without being capable of reproducing heat when once really consumed, is extremely useful for temporarily storing such heat as cannot be immediately utilised in order to impart it to the fluid or other substance which is employed in continuation of the operation of heating or of generating force.

Without troubling you with an account of the gradual progress of these improvements, I will describe to you shortly the furnace which I now employ for melting steel. This consists of a furnace bed made of very refractory material, such as pure silica sand and silica or Dina's brick, under which four regenerators or chambers filled with checkerwork of brick are arranged in such a manner that a current of combustible gas passes upward through one of these regenerators, while a current of air passes upwards through the adjoining regenerator, in order to meet in combustion at the entrance into the furnace chamber. The products of combustion, instead of passing directly to the chimney as in an ordinary furnace, are directed downwards through the two other regenerators on their way towards the chimney, where they part with their heat to the checkerwork in such manner that the highest degree of heat is imparted to the upper layers, and that the gaseous products reach the chimney comparatively cool (about 300° F.) After going on in this way for half-an-hour, the currents are reversed by means of suitable reversing valves, and the cold air and combustible gas now enter the furnace chamber, after having taken up heat from the regenerator in the reverse order in which it was deposited, reaching the furnace therefore nearly at the temperature at which the gases of combustion left the same. A great reversion of temperature within the chamber is the result, and the two first-mentioned regenerators are heated to a higher degree than the latter. It is easy to conceive that in that way, heat may be accumulated within the chamber to an apparently unlimited extent, and with a minimum of chimney draught.

Practically the limit is reached at the point where the materials composing the chamber begin to melt. Whereas a theoretical limit also exists in the fact that combustion ceases at a point which has been laid by St. Clair Deville at 5000° Fah., and which has been called by him the point of dissociation. At this point hydrogen might be mixed with oxygen and yet the two would not combine, showing that combustion really only takes place between the units of temperature of about 500° and 4,500° Fah.

To return to the regenerative gas-furnace. It is evident that there must be economy where, within ordinary limits, any degree of heat can be obtained, while the products of combustion pass in the chimney only 300° hot. Practically a ton of steel is melted in this furnace with 12 cwt. of small coal consumed in the gas-producer, which latter may be placed at any reasonable distance from the furnace, and consists of a brick chamber containing several tons of fuel in a state of slow disintegration. In large works, a considerable number of these gas-producers are connected by tubes or flues with a number of furnaces. Collateral advantages in this system of heating, which is now extensively used in this and other countries, are that no smoke is produced, and that the works are not encumbered with solid fuel and ashes.

It is a favourite project of mine, which I have not had an opportunity yet of carrying practically into effect, to place these gas-producers at the bottom of coal-pits. A gas shaft would have to be provided to conduct the gas to the surface, the lifting of coal would be saved, and the gas in its ascent would accumulate such an amount of forward pressure that it might be conducted to a distance of several miles to the works or places or consumption. This plan, so far from being dangerous, would insure a perfect ventilation of the mine, and would enable us to utilise those waste deposits of small coal (amounting on the average to 20 per cent.) which are now left unutilised within the mine.

Another plan of the future which has occupied my attention is the supply of towns with heating gas for domestic and manufacturing purposes. In the year 1863 a company was formed, with the concurrence of the corporation of Birmingham, to provide such a supply in that town at the rate of 6*d.* per 1,000 cubic feet: but the Bill necessary for that purpose was thrown out in the Committee of the House of Lords because their Lordships thought that if this was as good a plan as it was represented to be, the existing gas companies would be sure to carry it into effect. I need hardly say that the existing companies have not carried it into effect, having been constituted for another object, and that the realisation of the plan itself has been indefinitely postponed.

Coal Question.—Having now passed in review the principal applications of fuel, with a view chiefly to draw the distinction between our actual consumption and the consumption that would result if our most approved practice was made general; and having, moreover, endeavoured to prove to you which are the ultimate limits of consumption which are absolutely fixed by theory, but which we shall never be able to realise completely, I will now apply my reasoning to the coal question of the day.

In looking into the "Report of the Select Committee appointed to Inquire into the Causes of the present Dearness of Coal," we find that in 1872 no less than 123,000,000 tons of coal were got up from the mines of England and Wales, notwithstanding famine prices and the colliers' strikes. In 1862 the total getting of coal amounted to only 83,500,000, showing a yearly average increase of consumption of 4,000,000 tons. If this progressive increase continues, our consumption will have reached, thirty years hence, the startling figure of 250,000,000 tons per annum, which would probably result in an increase of price very much in excess of limits yet reached. In estimating last year's increase of price, which has every appearance of being permanent, at 8*s.* per ton all round, and after deducting the 13,000,000 tons which were exported abroad, we find that the British consumer had to pay 44,000,000*l.* more than the market value of former years for his supply of coal—a sufficient sum, one would think, to make him look earnestly into the question of "waste of fuel," which, as I shall presently be able to show, is very great indeed. The Select Committee just quoted sums up its report by the following expression:—"The general conclusion to be drawn from the whole evidence is, that though the production of coal increased in 1872 in a smaller ratio than it had increased in the years immediately preceding, yet if an adequate supply of labour can be obtained, the increase of production will shortly keep pace with that of the last few years."

This is surely a very insufficient conclusion to be arrived at by a Select Parliamentary Committee after a long and expensive inquiry, and the worst of it is, that it stands in direct contradiction with the corrected table given in the same report, which shows that the progressive increase of production has been fully maintained during the last two years, having amounted to 5,826,000 for 1871, and 5,717,000 for 1872; whereas the average increase during the last ten years has only been 4,000,000 tons. It is to be hoped that Parliament will not rest satisfied with such a negative result, but will insist to know what can be done to re-establish a proper balance between demand and supply of coal in preventing its conversion into smoke or other equally hurtful or useless forms of energy.

In taking the 105 million tons of coal consumed in this country last year for our basis, I estimate that, if we could make up our minds to consume our coal in a careful and judicious manner, according to our present lights, we should be able to reduce that consumption by 50 million tons. The realisation of such an economy would certainly involve very considerable expenditure of capital, and must be a work of time, but what I contend is that our progress in effecting economy ought to be accelerated in order to establish a balance between the present production and the ever-increasing demand for the effects of heat.

In looking through the statistical returns of the progressive increase of population, of steam power employed, and of production of iron and steel, &c., I find that our necessities increase at a rate of not less than 10 per cent. per annum, whereas our coal consumption increases only at the rate of 4 per cent., showing that the balance of 6 per cent. is met by what may be called our "intellectual progress." Now considering the enormous margin for improvement before us, I contend that we should not rest satisfied with this rate of intellectual progress, which involves an annual deficit of 4,000,000 tons to be met by increased coal consumption, but that we should bring our intellectual progress up to the rate of our industrial progress, by which means we should make the coal production nearly a constant quantity for several generations to come; by which time our successors may be expected to have effected another great step in advance towards the theoretical limit of effect, which, as we have seen, lays so far above any actual result which we have as yet attained to, that an annual consumption of 10 million tons would give more than the equivalent of the heat energy which we actually consume, *Solar Heat.*—I have endeavoured to show, in the early part of this lecture, that all available energy upon the earth, excepting the tidal wave, is derived from the sun, and that the amount of heat radiated year by year, could be measured by the evaporation of a layer of water 14 ft. thick, spread over the entire surface, which again would be represented by the combustion of a layer of coal, covering our entire globe, 1 ft. in thickness. The amount of heat radiated away from the sun would be represented by the annual combustion of a thickness of coal 17 miles thick, covering its entire surface, and it has been a source of wonderment with natural philosophers how so prodigious an amount of heat could be given off year after year without any appreciable diminution of the sun's heat having become observable.

Recent researches with the spectroscope, chiefly by Norman Lockyer, have thrown much light upon this question. It is now clearly made out that the sun consists near the surface, if not throughout its mass, of gaseous elementary bodies, and in a great measure of hydrogen gas, which cannot combine with the oxygen present, owing to great elevation of temperature (due to the original great compression) which has been estimated at from 20,000° to 22,000° Fah. This chemically inert and comparatively dark mass of the sun is surrounded by the photosphere where the gaseous constituents of the sun rush into combustion, owing to reduction of temperature in consequence of their expansion and of radiation of heat into space; this photosphere is surrounded in its turn by the chromosphere, consisting of the products of combustion, which, after being cooled down through further loss of heat by radiation, sink back, owing to their acquired density, towards the centre of the sun, where they become again intensely heated through compression and are dissociated or split up again into their elements at the expense of internal solar heat. Great convulsions are thus continually produced upon the solar surface, resulting frequently in explosive actions of extraordinary magnitude, when masses of living fire are projected a thousand miles or more upward, giving rise to the phenomena of sun-spots and of the corona which is visible during the total eclipses of the sun. The sun may therefore be looked upon in the light of a gigantic gas-furnace, in which the same materials of combustion are used over and over again.

It would be impossible for me at this late hour to enter deeper upon speculations regarding the "regeneration of the sun's heat upon its surface," which question is replete with scientific and also practical interest, because Nature is our safest teacher, and in comprehending the great works of our Creator we shall learn how to utilise to the best advantage those stores of potential energy in the shape of coal which have providentially been placed at our disposal.

COALS AND COAL PLANTS*

PROF. WILLIAMSON said that his distinguished friend, their president, had spoken the truth to a certain extent; but at the same time there was in what he had said a slight measure of what a particular school would call the *suggestio falsi.* He believed that if a balance of account could be struck between them it would be found that he (the lecturer) was enormously the gainer from the fact that he enjoyed the same name as the president. As far as he could arrange the balance it was this—that their president was debtor one dinner which he (the lecturer) always contended his friend had got because he had received a card of invitation which did not belong to him—while, on the other hand, there was an item of credit to the extent of all the learning the president displayed at every meeting of the British Association, but for which, at least in the North of England, he (Prof. W. C. Williamson) was usually credited. Under these circumstances he thought it would be seen that instead of his being the loser he was in reality an enormous gainer.

He remembered a distinguished friend of his, a member of the House of Commons, telling him that whenever an individual rose in that house to speak on a subject on which he was known to have written a book, the house speedily became emptied, because the members were alarmed at the idea of a speech from a man who had an inveterate hobby. He presumed, however, that he stood there that night simply because he had a hobby; but he would promise not to ride it too far or inflict it too long upon his audience. Furthermore when he remembered how short was the time since Prof. Huxley had addressed a Bradford audience on the subject of coal, he was somewhat appalled at his own boldness in having ventured to deal with a similar matter at the present moment. But luckily for him science did not stand still, and although so short a time had elapsed since Prof. Huxley had delivered the lecture referred to, there was much now to be said on the subject which could not have been said then. Still, with the magnificent address of Prof. Huxley within reach, it would not be necessary to detain the auditory long on the general theories which were now so widely accepted with reference to the origin of coal.

Prof. Phillips, in his address to the Geological Section on the previous morning, had reminded them how short a time it was—the period being within his own life-time—since the vegetable origin of coal was broadly and openly disputed. It would, however, be difficult now to find any one at all enlightened on the subject who would venture to dispute that the origin of coal was vegetable. In the same way another hypothesis—known by the title of the drift theory—had once been very generally accepted. Men who admitted the conclusion that coal had once been a mass of vegetable life differed as to the method by which that vegetable mass had found its way into its present position. The majority of the older geologists believed that coal had been conveyed into those positions by water—that large quantities of vegetable material had been brought down great rivers like the Mississippi or the Ganges, that these vegetable rafts, as they might be termed, had accumulated in the estuaries and the ocean, and that when they had become thoroughly water-logged, they had sunk to the bottom and formed accumulations of vegetable elements sufficient to constitute the existing coal-beds. Thanks to the labours of a series of indefatigable workers like the late Mr. Bowman, Mr. Binney, Sir Wm. Logan, and others, we now had a clearer and much more probable conception as to what coal originally was.

It must be understood that although the earth was popularly regarded as the type of everything that was stable and immovable, this was a very erroneous idea; for old mother earth was about one of the most fickle and inconstant of all the jades with which men had deal. She was never still. It happened that at the present day there were certain regions, such as the volcanic regions, which were always moving upwards, like the more aspiring of the youths of Bradford, while there were others, such as the coral regions, which were steadily going downward, like those less fortunate youths who did not succeed in the race of life. So it had been in the olden time. The coal beds appeared to have accumulated in the latter class of areas—the areas of depression—geographical areas in which the earth had a tendency to sink below the level of the ocean. Upon such areas mud and silt had accumulated until the deposit thus formed had reached the level of the water, and then came what would appear to have been highly necessary as a preliminary to the growth of the coal material, namely, a bed of blue mud. It was not known why that blue mud was there or whence it came, but it was as certain as that garden plants required favourable soils for their development, that whatever its cause the blue mud was the soil which seemed to have been preferred by the great majority of the plants constituting the forests of the carboniferous era. In it the minute spores or seeds of the vegetables which afterwards became coal, germinated and struck root, until eventually the muddy soil became converted into a magnificent and almost tropical forest. As the forest grew the spores fell from the trees, the half-dead leaves and decayed branches also dropped, and by-and-by the stems themselves gave way, and thus was accumulated an immense amount of vegetable matter. This, in the progress of time, sank below the water level, and more mud being deposited on the top of the coal, the new formation in turn underwent the same processes as its predecessors, until at length a new forest was formed to share the same fate as that which had gone before it. The process was repeated again and again, until at length we had an accumulation of materials, mixtures of the various substances he had spoken of, alternating with beds of coal, until we had a vertical thickness of rock varying from three, four, or five, to as much as eight or ten thousand feet.

But while these general truths were accepted with little or no reservation, there were one or two points contained in Prof. Huxley's lecture upon which he would venture for a moment to dwell. In that lecture he properly laid stress upon certain minute bodies that were found in the interior of coal.

[The lecturer here pointed to a diagram representing a vertical

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* Abstract of Lecture delivered before the British Association, at Bradford, by Prof. W. C. Williamson, F.R.S.